U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

FAR GUIDANCE MATERIAL

Subject: DESIGN CONSIDERATIONS CONCERNING THE USE OF TITANIUM IN AIRCRAFT TURBINE ENGINES	**Date:** 7/28/83 **Initiated by:** ANE-110	**AC No:** 33-4 **Change:**

1. PURPOSE. This circular provides guidance and acceptable means, not the sole means, by which compliance may be shown with the design requirements of Part 33 to minimize the probability of the occurrence of an internal fire when titanium is used in aircraft turbine engines.

2. APPLICABLE REGULATIONS. Part 33, Sections 33.17(f) and 33.19.

3. REFERENCES.

a. Report No. FAA-RD-79-51, "Titanium Combustion in Turbine Engines," July 1979 . (NTIS Accession Number AD A075 657).

b. British Civil Airworthiness Requirements, Appendix to Chapter C3-2, Paragraph 3, Titanium Fires, dated August 28, 1981.

4. BACKGROUND. Titanium is used in aircraft engines because of its low density, high specific strength, and corrosion resistance. While these are significant benefits, titanium has some unique properties that make it unsuited for some applications within turbine engines. Particularly, titanium has two properties that can combine to make it vulnerable to combustion: (1) unlike most other structural metals, titanium ignites at a lower temperature than it melts, and (2) it has a lower conductivity of heat. Thus, heat may not be readily conducted away from its source, thereby permitting the titanium to more rapidly reach its ignition temperature. Hard rubs are the most common source of heat. Rubs may result from foreign object damage (FOD), secondary damage, stall, bearing failure, unbalance and/or case deflection. During a rub, the low thermal conductivity titanium component may rapidly rise to the ignition temperature.

There have been over 140 known instances of titanium fires in aircraft turbine engines in flight and during ground tests. A few of these instances have been serious from a flight safety point of view. A fair proportion have resulted in significant damage to the engine and could under some circumstances be hazardous. In almost all these instances, the titanium fire was a secondary event where something else failed first and resulted in a situation which caused some titanium part to be heated to its ignition temperature. Usually this failure was a titanium compressor blade that failed from foreign object ingestion, vibration, a heavy rub, or some other occurrence. For example, a broken blade when lodged in a location where it is rubbed by a rotating component can be heated by friction to its ignition temperature. Once ignited, titanium combustion continues until either the titanium is depleted, the air pressure falls below some critical value, the combustion progresses to a heavy section, or the ignition energy source is removed. Titanium fires are fast burning, i.e., 20 seconds or less, and are extremely intense. The molten particles in titanium fires generate highly erosive hot sprays which have burned through compressor casings with resulting radial expulsion of molten or incandescent metal.

With the increased use of titanium in commercial air carrier service, several significant service incidents occurred which indicated the need for a better understanding of the nature of titanium combustion. The National Bureau of Standards under contract to the Federal Aviation Administration studied the problem and produced a report (reference (a)) which summarized available information on:

(a) The use of titanium in turbine engines and service experience with it, and

(b) The theoretical and experimental research on the titanium combustion phenomena.

The information in reference (a) provides the basis for the design considerations listed in paragraph 5 of this Advisory Circular.

The British Civil Aviation Authority has specified in reference (b) that it will normally be assumed a titanium fire is possible if stationary titanium material exists in areas where:

a. Pressure will exceed 200 kN/m^2 (29.4 lbf/in^2); and

b. Relative air velocities are in excess of approximately 50 m/sec (150 ft/sec); and

c. The geometry is such that relatively thin titanium sections exist which can be rubbed, directly or after shedding, by rotating parts. Stator blades of conventional design, of up to 15 cm (6 in.) of airfoil height are regarded as falling into this category.

The National Aeronautics and Space Administration and U.S. Air Force are sponsoring contractual, university, and in-house research programs to provide guidance on the use of titanium in engines such that only unsustained combustion would occur under abnormal operating conditions. These programs pertain to titanium combustion fundamentals, rub energetics, blade coatings, and new alloys.

5. <u>DESIGN CONSIDERATIONS</u>. § 33.17(f) of the Federal Aviation Regulations requires that: "The design and construction of turbine engines must minimize the probability of the occurrence of an internal fire that could result in structural failure, overheating, or other hazardous conditions." To comply with this requirement ideally, there should be no titanium in the gas path of turbine engines. However, the properties of titanium are such that to prohibit its use in

certain rotating parts of the engine would significantly increase engine weight. Fortunately, experience indicates this extreme position is not necessary. The application of titanium in the engine design should be directed primarily to minimizing the probability of uncontained titanium fires, i.e., fires that penetrate the engine casing. Design features that minimize the possibility of ignition and propagation of combustion will aid in achieving the primary objective and overall engine reliability.

Reference (a) has a section on the precautions and preventative measures that can be used to assist in the design of aircraft turbine engines when titanium is to be used. The following considerations are based on proven design experience and should be followed in evaluating the use of titanium in engines; however, they are not necessarily the only means available to the designer.

a. Path of combustion products. When titanium materials are used in an engine design, an analysis should be made of the paths the products of combustion will take to verify that a titanium fire will be contained within the engine. If these molten products can result in failures that are uncontained or other hazardous conditions, the design should be changed to prevent these possibilities.

b. Compressor casing. The design, construction, and materials used for the compressor casing must provide for the containment of fire and consequential damage in compliance with FAR §§ 33.17(f) and 33.19. The compressor casing in areas where titanium combustion may occur should not be of titanium unless it is suitably protected to prevent an uncontained fire and its consequential damage.

c. Compressor stator vanes. The design, construction, and materials used for compressor stator vanes must conform to the containment requirements as specified in FAR § 33.17(f). The compressor stator vanes should not be of titanium if ignition can result in uncontained fire. Experience shows that forward stages can be excepted if the vanes are large enough and/or shrouded to avoid breaking during foreign object ingestion.

d. Seals. The design, construction, and materials used for seals must conform to the requirements of FAR § 33.17(f). The use of titanium for either the rotating or stationary part of seals should have design features that inhibit ignition and minimize the possibility of propagating combustion.

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